FINE STRUCTURE IN THE EAST-WEST COSMIC-RAY INTENSITY AT LAHORE ($\lambda = 22^{\circ}$N), INDIA*

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Part I

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ABSTRACT The paper deals with the fine-structure measurements taken at Lahore ($\lambda = 22^{\circ}$N) in 1947 and their statistical analysis by the method developed by Warren. A triple coincidence telescope, consisting of three internally quenched G. M. counters, 35 cm long, 2.5 cm in diameter, with a distance of 25 cm between the extreme counters, has been employed. The intensity measurements have been made in both the eastern and western azimuths from $0-42^{\circ}$ at 6 degree steps.

The results indicate a possibility of the existence of the negative primaries. However, to have a significant decision about this point we need more data. The presence of silicon band (13.2 B ev) in the primary cosmic-rays is definitely shown, its edge extending to about 21° in the east of the zenith. This supports earlier experiments by Millikan and his co-workers in India and the banded nature of the primary cosmic-rays.

A comparison between our results and those of Schremp and Banos, at Mexico, ($\lambda = 29^{\circ}$N) shows a striking similarity as regards the west-east excess. Any divergence has been traced to be due to the difference in latitude of the two places. The oxygen band (7.5 B ev) and the nitrogen band (6.5 B ev) which are effective in the western azimuth at Mexico do not show up at Lahore, and this explains all the differences. The work brings out the importance of such measurements and emphasises the need of more extensive observations at such latitudes with coordinated programme.

INTRODUCTION

On the considerations of the banded nature of penumbra (*i. e.* regions of allowed and forbidden energy bands) Schremp (1938) stated that for intermediate latitudes (10°-40°), the penumbra will exhibit its most important aspect, giving rise to a highly anomalous behaviour of the directional intensity distribution of cosmic-rays. The theory of this anomalous intensity distribution, termed as 'Fine-structure', involves the geo-magnetic effects on the primary energy spectra at infinity and the absorptive effects on their passage through the atmosphere. Both of thsese effects account for the prominences and depressions observed in the zenith angle-intensity distribution curves.

The first experimental evidence of the existence of fine-structure came from the work of Cooper (1939, 1940) and Ribner (1939), at Missouri ($\lambda = 49^{\circ}$) and from the extensive work of Schremp and Banos (1940, 1941) at Mexico

* The data of the present work were collected at Lahore in 1946-47.

Cooper (*loc. cit*) found three approximately symmetrical prominences (*i.e.*, increase of intensity over the normal $\cos^2 z$ (z=zenith angle) distribution) at $z=5-10°$, 20° and 40° and Ribner (*loc. cit*) obtained one pair of symmetrical prominences at 20° both in the eastern and western azimuths together with an indication of peaks in the neighbourhood of 10° and 40°.

Vallarta (1939) has emphasised the importance of such studies, as they can be useful in the analysis of primary cosmic rays, their energy spectra at infinity and their behaviour on the passage through the atmosphere. In addition, this type of study can help in the elucidation of the hypothesis of atom-annihilation energy bands present in the primary cosmic radiation.

Millikan (1949) has shown that the silicon band of energies should appear vertically at 20°N in India. Millikan (1947) has further stated that so far as India is concerned, this hypothetical band may properly be said to predict and explain both qualitatively and quantitatively the latitude (and other directional) effects. The existence of this band was shown from a series of balloon flights made in India [Neher and Pickering (1942); Millikan, Neher and Pickering (1942)] during 1939-40, using Geiger counters in vertical double coincidence. The most significant point, that was observed, was that within the uncertainty of measurements, there was no change in the intensity of radiation coming in near the vertical from 3-17°N, while from 17-25°N, there was an increase of 21%. This increase was interpreted to be due to primary charged particles in the energy range 15 down to 11 5 B ev, thus indicating the existence of the supposed Si band. It is seen that this band will be effective at the latitude of Lahore (22°N) and should produce some observable effect in the east-west intensity distribution.

Further, as indicated above, Schremp (*loc. cit*) has (see also Bhattacharya, 1942) attributed this fine structure to the effects of penumbra. However, the most extensive work on fine structure at the high latitude of Missouri does not corroborate the above view. Even if the effect of penumbra is not negligible, the azimuthal symmetry of the fine structure, as observed at Missouri and Mexico, cannot be understood in terms of penumbra effects. Instead, it seems that the fine-structure is due to a discrete energy spectrum of primary particles showing up as a result of the 'main cone' or 'Full light' in appropriate directions in the sky. Since the work of Johnson (1938) shows that the primaries are mainly (or entirely ?) positively charged and since the most effective energy band at Lahore is 14 B ev band (corresponding to the silicon band), the appearance of main cone should be a step-function ' ‾| ' the intensity being higher to the west where the primaries of the given energy are allowed than to the east where they are not.

Realising the importance of these points and the information that can be obtained from the directional studies in deciding these, the present study of the fine-structure in the intensity distribution in the E-W azimuths was undertaken at Lahore ($\lambda=22°$N). The importance of this work is further shown from the fact that there is not much data of this type for these latitudes, the only work, existing, being of Schremp and Banos (*loc. cit.*) at Mexico (29°N).

APPARATUS AND EXPERIMENTAL PROCEDURE

The cosmic-ray telescope (Parkash and Sarna, 1948) used in the present work consisted of three internally quenched G. M. counters, 35 cm long, 2.5 cm in diameter, mounted in parallel positions on a light wooden frame. The distance between the extreme counters was 25 cm. The telescope subtended an angle of 11.3° in the zenith, though as shown by Cooper (*loc. cit.*) the actual resolution is much better than the dimensions indicate. For the present set-up more than half of the rays are incident through an angle of about 2° on each side of the mean zenith angle. The triple coincidences were recorded by a circuit (Parkash and Sarna, 1948) after its thorough testing for discrimination against doubles and singles. With the plane of the telescope in the magnetic meridian so that the rotation would be in the local east-west plane; the observations were taken at every 6° intervals, ranging from 0-42° in the eastern and western azimuths. The telescope was alternately kept inclined towards east and west at a particular zenith angle for about half an hour, and the process repeated. The total number of counts in each position was calculated and reduced to a common temperature and pressure of 20°C and 74.5 cm of Hg respectively. The probable errors were calculated as usual.

RESULTS AND DISCUSSION

At sea level, the zenith angle-intensity curve is represented by the square of the cosine of the zenith angle. Thus if I_0 is the vertical intensity, at any zenith angle z, then $I_z = I_0 \cos^2 z$ and the observed anomalies are represented by $\Delta z = I_z - I_0 \cos^2 z$. As Cooper (*loc cit.*) has remarked, it is

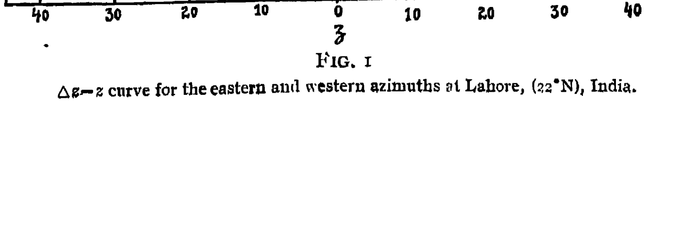

FIG. 1

$\Delta z - z$ curve for the eastern and western azimuths at Lahore, (22°N), India.

more convenient to plot the deviation Δz or per cent Δz for the empirical cos square curve against z than the zenith angle-intensity curve. This flattens out the distribution curve and shows any prominences and depressions as oscillatory about a perfect cos square distribution. Table I gives the results of the present measurements. Fig. 1 is a plot of the percentage deviation Δz against z. The arrows show the extent of probable errors.

TABLE I

Fine-structure data in the eastern and western azimuths at Lahore (22°N), India.

Zenith angle (z), degrees	Time in minutes	Total number of counts at 20°C and 74.5 cm Hg	Counts/min $I_z \pm pe$	$I_0 \cos^2 z \pm pe$	$\Delta z \pm pe$ $\Delta z = I_z - I_0 \cos^2 z$	Per cent $\Delta z \pm pe$ $= \left(\frac{I_z}{I_0 \cos^2 z} - 1\right) 100$
0* (vertical)	2370	7909	3.337 ± 0.025	3.337 ± 0.025	0.000	0
6	W 340	1157	3.402 ± 0.067	3.304 ± 0.025	+0.098 ± 0.072	+0.030 ± 0.022 (X100)
	E 319	1017	3.188 ± 0.067		−0.116 ± 0.072	−0.035 ± 0.022
12	W 471	1562	3.316 ± 0.056	3.193 ± 0.024	+0.123 ± 0.061	+0.039 ± 0.019
	E 427	1268	2.968 ± 0.056		−0.225 ± 0.061	−0.070 ± 0.019
18	W 472	1476	3.127 ± 0.055	3.018 ± 0.023	+0.109 ± 0.060	+0.036 ± 0.020
	E 420	1237	2.945 ± 0.056		−0.073 ± 0.061	−0.024 ± 0.020
24	W 443	1209	2.729 ± 0.053	2.785 ± 0.021	−0.056 ± 0.057	−0.020 ± 0.020
	E 431	996	2.311 ± 0.049		−0.474 ± 0.053	−0.170 ± 0.019
30	W 651	1610	2.473 ± 0.041	2.502 ± 0.019	−0.029 ± 0.045	−0.011 ± 0.018
	E 595	1235	2.083 ± 0.040		−0.419 ± 0.044	−0.167 ± 0.017
36	W 593	1250	2.108 ± 0.040	2.185 ± 0.016	−0.077 ± 0.043	−0.035 ± 0.020
	E 666	1228	1.841 ± 0.035		−0.341 ± 0.038	−0.156 ± 0.017
42	W 409	725	1.772 ± 0.044	1.844 ± 0.014	−0.072 ± 0.046	−0.039 ± 0.025
	E 402	590	1.468 ± 0.041		−0.376 ± 0.043	−0.204 ± 0.023

Some of the marked peculiarities apparent from Fig. 1 are:

(i) A very marked west-east excess, similar to one observed by Schremp and Banos (*loc. cit.*) in the Mexico curve.

(ii) There is a prominence at 18° in the eastern azimuth together with an indication of another at 36° and a flat prominence at about 12° with an indication of another at 30° in the western azimuth. It may be noticed that the magnitudes of these 'anomalies' is greater in the eastern than in the western azimuth.

(iii) The intensity falls off less rapidly in the west than in the east.

* Vertical counts were recorded daily, twice, during the period of observations and the average counting rate obtained after applying temperature and pressure corrections.

iv. There are two depressions at 12° and 24° in the east and an indication of one at 24° in the west.

The 18°E prominence, also present in Mexico curve, is believed by Schremp and Banos (*loc. cit.*) to be due to the presence of negative primaries. In fact, the existence of negative primaries has been shown (Swann, 1933) to be necessary, even otherwise. Vallarta *et al* (1939) have shown the existence of negative primaries from the considerations of data on diurnal variations. Though the sea level effects seem to be mostly due to positive particles, they may not be really due to the excess of positives over the negatives but merely due to the difference in the penetrating power of the two types of primaries, (Evans, 1941); or it may be that there is an excess of negative slow primaries (Alfven, 1938), which might get absorbed in the upper parts of the atmosphere by a process different from that of the positives, (Vallarta and Bouckart, 1935). Janossy (1948) is also of the opinion that the primaries are of two types, probably electrons and protons. The recent rocket experiments of Singer (1950), the balloon experiments of Hulsizer and Rossi (1948) and of Schein, Jesse and Wollan (1941) and the high altitude experiments on E-W asymmetry by Johnson and Barry (1939) have proved the non-existence of electrons as the primary particles. If now we exclude the possibility of electrons as the negative primaries, then negative protons (Arley, 1946) may form the negative primaries. Even on Millikan's atom-annihilation hypothesis, Klein (1950) has shown that, for the annihilation to take place, there must be the presence of anti-matter near ordinary matter in the inter-stellar space; the two atoms of matter and anti-matter annihilating themselves on collision and generating two primary cosmic-rays which may be protons and anti-protons. These anti-protons, on reaching the top of the atmosphere, might interact with matter in a different way from the protons. That this is so, is, in a way, evident from the measurements on the directional dependence of the positive excess in the meson spectrum. Quercia, *et, al* (1950) have found a marked difference in the relative abundance of negative and positive mesons in the eastern and western azimuths There are relatively more negative mesons than the positives in the east and vice versa.. (This may be explained either (*i*) on the supposition that higher energy positive primaries reaching the eastern azimuths produce mesons in a different way than the lower energies reaching the western azimuth, or, (*ii*) there are negative primaries (negative protons) which somehow produce more negative mesons. The latter view appears more justified in view of the evidences from other sources).

The relatively rapid and greater decrease of intensity in the east, clearly seen in Fig. 1, may be attributed to the presence of negative primaries (negative protons) which, along with their progeny, are absorbed more quickly while traversing down the atmosphere. The prominence at 18°E in Fig. 1 also supports this view. (The prominence at Lahore is less marked than at Mexico. This is due to the fact, that, the edge of positive primaries of 13.2 Bev nearly extends to this angle, while at Mexico this extends to farther east. Thus, the contribution of the positive component being nearly zero at 18°E at Lahore, the prominence is not so marked.)

The marked west-east excess, present in both Lahore and Mexico curves, is probably due to the presence of the already mentioned silicon band (13.2 Bev) with its edge extending to the east of zenith to about 18-24° at Lahore and farther east at Mexico. That, there is such a band of energies, with its edge at about 18—24°, is clearly shown by the marked depression at 24° in the eastern azimuth. This might correspond to 36° depression in Mexico curve. The depression at 12°E, if real, probably indicates the presence of another narrow band within the silicon band.

The western azimuth does not show anything real beyond statistical fluctuations, though there is an apparent anomaly near the zenith. The anomalies observed at 12° and 42° in the western azimuth in Mexico curve, but absent from ours, seem most probably due to the presence of positive primaries of the oxygen band (7.5 Bev) and the nitrogen band (6.5 Bev) effective at that latitude (29°N) but absent from Lahore (22°N), India, due to geo-magnetic cut-off.

From the present investigation, therefore, we conclude that:

i. Negative primaries (probably negative protons) form a part of the primary cosmic-rays.

ii. Most of the west-east excess is due to the presence of the silicon band, of which, the existence is definitely shown, thus supporting the atom annihilation hypothesis, as modified by Klein, as the major source of cosmic rays.

iii. In conjuction with Mexico data, the banded nature of the primaries is responsible for fine-structure.

The above discussion clearly brings out the importance of such measurements in deciding these vital issues. These are needed the most at intermediate latitudes where other atom annihilation bands will also show their peculiarities. The existing data are very meagre and a coordinated programme using similar equipment is desired.

Part II

STATISTICAL ANALYSIS OF LAHORE DATA

In order to see the significance of the above conclusions, the data of Part I have been analysed by the method developed by Warren (1946). Whereas, we have visualised the fine-structure as departures from the normal cos square curve, here we consider it as departures from the log I_z-log $\cos_n Z$ curve which under normal distribution is a straight line.

Table II gives the summary of the interpretations of Lahore data. Fig. 2 is the logarithmic plot of cosmic-ray intensity measured at Lahore. The

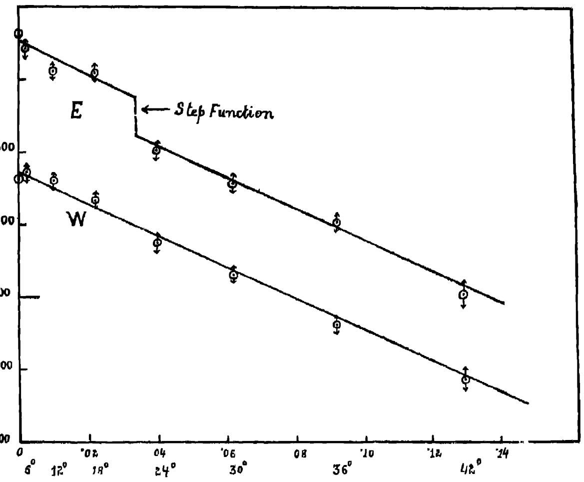

FIG. 2

Logarithmic graph of cosmic-ray intensity measured at Lahore. The ordinates are the logarithms of the relative intensities and abscissae are the negative logarithms of the cosine of z.

ordinates are the logarithms of cosmic-ray intensity and the abscissae are the negative logarithms of the cosine of the zenith angles.

TABLE II

SUMMARY OF INTERPRETATIONS OF LAHORE DATA

Name of fitted line (s)	points fitted	Parameter values a_1	a_2	b_1	b_2	χ^2	N	$P(>\chi^2)$
Single line for all	all, E & W	·4343		2·54		84 1	13	10^-6
Single line W	all, in W & 0°	4430		2.173		5 299	6	51
" E	all in E & 0°	4046		2 873		19 20	6	005
Combined, both of above	all, 0° twice					21 50	12	018
Step function, E combined with single line W.	all in E & 0°	4313	·3718	2 218		6 07	5	224
	all, 0° twice					12 27	11	·35
Step function, only one step at 21°E (parallel lines with a break)	all	4400	·3689	2.124		15 91	12	.196
Step function, two non parallel lines, with a break at 21° E.	all	·4398	·3684	2.133	2.120	15·9	11	15

* (For various constants, refer to Warren (*loc.cit.*).

As mentioned in Part I, the appearance of the main cone should be a step function '⅂' giving higher intensity to the west where the primaries are allowed than to the east where they are not. We, therefore, tried to fit the data with the use of such a step function. It is evident from Fig. 1, that it is easy to fit a straight line inside of six out of eight of the probable errors. Since there remains six degrees of freedom and the probable error is selected so that there is an equal chance of the discrepancy falling inside and outside the limit, we see that we can do better than the expected three outside, even from this crude consideration. The more detailed calculations verify this exactly and the agreement between the observations and a single straight line (on the log-log graph) is exactly as good as would be expected from the observational errors; or we might infer (as we mentioned in Part I) that the data in the west do not show anything that can be reliably distinguished from statistical fluctuations. To be convincing of the break between 18° and 24° in the west, the counting errors should be one third or ten times as many counts recorded per point. (If real, this break will correspond to the edge of negative primaries with slight overlapping near the zenith. It may be mentioned that no other low energy bands (oxygen or nitrogen bands) are allowed at the place of observation).

In the east, however, the situation is quite different. Here the discrepancy is quite real and the calculations show only one chance in three hundred that these data were obtained from a 'true' distribution, that is a single straight line. Here we have an example of this simple type of fine-structure with a single energy band of positive primaries that appears only west of this limit. This can be calculated as a step-function by fitting parallel straight lines to the observations in the east of azimuth. This gives a good probability of agreement (1 in 4.5) and appears to fit in quite readily with the simple interpretations given above. The step at 21° E appears to be due to the edge of the silicon band (13.2 Bev) extending to about 18-24° in the east of the zenith and, hence, established its existence.

The marked west-east excess, as stated in Part I, is also due to this band of positive primaries.

To decide the point that the step at 18-24° E might be the only statistically significant irregularity, we tried to fit a single straight line to all the points in both the azimuths west of this edge and a parallel line (or non-parallel) to the east of it. The probability of agreement is 1 in 5 (1 in 6.5) showing a very good agreement with the hypothesis that the western excess is due the single edge in the east between 18-24° E, corresponding to about .50 millistormers or about 14 Bev. However, to decide about other conclusions apparent from our observations, we need more data.

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